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ELECTRONICS MIXED-MODE SIMULATION

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Mixed-mode simulation is an engineering software tool that electrical engineers are now using to design and/or analyze and troubleshoot electronic circuits that have analog as well as digital circuitry and componentry together, and can run a simultaneous simulation of them under the same environment.

The object in this report is to give the reader a thumbbnail sketch of this emerging technology's evolvement in the electronic industry, and to bring the reader up-to-date on the trends and methodologies popular in this industry.

Mixed-mode simulation, the latest offshoot of the computer aided engineering industry, appears to have arrived, after many false starts, as a bona fide and practical engineering tool.

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CONTENTS

INTRODUCTION

The computer simulation industry serves a diverse clientele that includes electrical engineering, where it has substantially reshaped the field. Other greatly influenced disciplines include chemical, structural and mechanical engineering, operations research, system analysis, industrial management and fluid mechanics, as well as, engineering managers in industry and government.

In electrical engineering, computer simulation was adopted since its inception. One of the earliest simulation programs, created mainly by electrical engineers, was developed with only electrical circuit problem solving in mind. But the demand for such engineering tools from other scientific disciplines and government have always been there. In the beginning the scope of coverage by one of these electronic simulation programs was rather modest, judging by the amount of discrete components (mainly by the number of transistors[1]) that it could handle. Later improvements in memory capacity and user-system graphics interface, suited electronic simulation to be used for solving large circuits and as part of large projects. Developers of simulation programs of this kind have always been concerned with the fact that electronic circuit problems in the two basic domains, the analog and digital domains, were more efficiently solved by inherently different programming approaches. This meant that each domain had to be treated separately. This concern could not be properly dealt with until the late 1980's with the advent of practical powerful computers that cold accommodate the advanced programming methodologies geared to overcome this hurdle. Some of these are covered later.

This is basically why a mixed-mode simulation program came to be developed and is now a necessary and forthcoming tool for systems design and analysis.

THE FUSION OF TWO WORLDS

A technology data gathering association in Boston, MA called the Technology Research Group, indicates that 80% of all printed circuit boards contain some small amount of analog circuitry. However, this can be in many instances, the most crucial circuitry on the board. For example, the most critical circuit in a dynamic random access memory (DRAM) board is the sense amplifier, which is analog in nature. In motor or engine controls where the sense and/or drive circuits are analog and the

[1] This has become a figure of merit and memory requirement factor (about a KByte per transistor to be simulated).

control equations are implemented digitally, separating the analog and digital sections does not result in an effective simulation of the control loop. On the other hand, in most electronic mine systems the 'brain' is usually a digital timer or a microcontroller which is a small portion of this basically analog system, and breaking up the analog and digital portions will not give a valid description of the entire electrical system.

In mixed-mode simulation, a valuable asset is feedback handling capabilities. In the past, for a simple circuit, feedback between the analog and digital sections was handled in the following manner: the analog and digital sections were identified and then analyzed and simulated separately. Next, a 'black-box' was created for each section with its respective input and output signals. Then only the outputs of one, which became inputs to the other and vice versa, were used for the simulation of each within its boundaries in its analog or digital domains, by its respective simulator. But being that feedback path values usually change with time, depending on the degree of feedback involved, it was necessary to run a new simulation every time these values changed or with each state of the feedback loop. This made the simulation process not only tedious and time consuming, but inaccurate and even useless in applications where the feedback loop rate is rapidly changing. Processing times for an application of this kind could take days as opposed to hours, or even minutes depending on the complexity of the circuit using a mixed-mode simulator.

In electrical engineering, all circuits are basically separated in two domains. The analog and digital domains. Both domains have basic different electrical characteristics and are even taught in different undergraduate and graduate courses. But, elementary electronic theory rules the principles of both. They are also treated differently in systems theory, where formulated methods apply only to one of the domains and not to the other.

In software engineering these two domains are approached, as expected, differently. This is mainly because of efficiency concerns as it will become evident later. Digital circuits are treated from a functional model[2] stand point. Components are represented by a simple Boolean description of states, and not by their real analog characteristics. In analog circuits, an improved version of the original simulation program with integrated circuit emphasis (Spice) program is often used; a program in which matrices are generated from sets of differential equations describing each node (nodal analysis) in the circuit to which the appropriate method is applied to solve this now purely mathematical problem.

[2]Components behave in a given number of ways for a given number of possible inputs.

The basic simulators for both the analog and digital domains have been available for many years. An integrated package only became viable, very quickly, in the 1990's when practical computational power was at hand to process all the algorithms that would allow both simulators to run in unison and when enhanced graphical system-user interface algorithms were developed.

The efficiency factor in a mixed-mode simulator is largely constrained by the analog part of the simulator because of its inherent speed disadvantage[3]. For a ratio of 10 to 1 of digital to analog parts, for example, more than 50% of the central processing unit's time will be required by the analog simulator. This will vary depending on the complexity of the parts involved.

Mixed-Mode Simulation Evolution

Most of the emerging mixed-mode simulators are based on or use an improved version of the original Spice program. This program describes circuits in terms of matrices that are generated from integration algorithms, which are obtained from a nodal analysis of the entire circuit.

There is nothing new about mixed-mode simulation. In fact, traditional analog circuit simulators like Spice, and even newer ones like Saber and others (fig. 1), can handle digital circuits just as easily as analog circuits; in fact, they can not tell the difference. It is when an engineer wants to connect analog signals with digital logic in the same circuit requiring simultaneous operation that a need for mixed-mode simulation arises.

Simulation Requirements

Accuracy, reliability, and most of all, practicality are the key factors when examining all the elements in a particular emerging technology. It is also easy to surrender to the spell of a technology that has promised to solve all of our engineering problems while fulfilling all of the above, and seemingly, has delivered.

A mixed-mode simulator must have the following three separate capabilities to perform mixed analog-digital simulation efficiently:

- The simulator must be able to handle both analog and digital device models.

[3]It has to process differential equations and numerical matrices as opposed to state tables for digital simulation.

- The simulator must use both event-driven algorithms for digital simulation and integration algorithms for analog simulation.

- The simulator should be particularly able to simulate feedback paths and interface between the analog and digital blocks. This is one way of saying that the event-driven and integration algorithms must be able to communicate with a common data bank and work in unison.

Other aspects of a different nature to consider are: component library size; availability of nonelectrical second-party models; behavioral models for both analog and digital; custom modeling support; electronic data interchange format interfaces (EDIF); hardware modelers or physical modelers, and options for other functions, such as automatic test generation for digital circuits and frequency analysis and multiple virtual laboratory testing equipment for analog circuits.

Typical Applications

Even in todays highly digital world analog circuits are still much in demand, as is software for designing them and simulating their coupled operation. Typical designs in the military, aerospace, telecommunications, and instrumentation industries include multiple analog and digital stages. These circuits filter and amplify incoming signals from outside sensors or telecommunications receivers. After an analog-to-digital (A-D) conversion, the resulting digital signals are processed by digital circuitry that can range from a few gates to sophisticated digital signal processing and applications specific integrated circuit chips. A final analog stage, preceded by a digital-to-analog (D-A) conversion, amplifies and filters control signals to drive external devices. A similar situation occurs in a more control where one has transducers and actuators that are analog and the control signals that are generated digitally, as explained earlier.

MIXED-MODE SIMULATION TECHNICAL PATHS

There are a number of ways to couple analog and digital simulators, and certain approaches are most appropriate for certain applications. In circuits, such as A-D converters and bus drivers, the one-way communication between the analog and digital portions is adequately served by a modest mixed-signal algorithm like a stage-by-stage (unidirectional coupling) simulation (see section on methodologies). But if the circuits are more complex, such as phase-locked-loops and DRAMs, a more sophisticated methodology is needed.

Other new simulators are employing multiple algorithms within the analog and digital domains that, at the appropriate times, are called as subroutines to deal with a given type of circuitry. This is proving to be very efficient and speedy.

A unified environment to track the entire verification, analysis, and simulation process is needed, as well as adequate simulation methodologies that can deal with the definition of the circuit at the functional level. After all, to electrons there are no analog parts or digital parts, they are all simply electronic circuits following the same laws of physics in their operation. Prices and computer platforms upon which these methodologies can be processed are shown in figure 1.

Methodologies

Most vendors of mixed-mode simulation software tools use basically six different methodologies to build them:

- Unidirectional coupling. Data can be sent only one way, digital-to analog or analog-to-digital, in a stage-by-stage simulation. Only one-way communication between the analog and digital portions is allowed. This has limited feedback capability.

- Loose bidirectional coupling I. Separate processes running on parallel or separate platforms with process synchronization. In other words, two simulators are used (one of each) to deal with a portion of the circuit in its appropriate domain with an underlying algorithm taking care of the synchronization of the two simulators. This is good for very large circuits.

- Loose bidirectional coupling II. Separate processes running on the same platform in a multitasking mode and with task prioritization rather than synchronization. Same as previously shown, but with the underlying algorithm processing the most complex tasks first and synchronizing it later. This is good for circuits with a medium amount of digital and analog circuitry and more feedback.

- Unified directly coupled (or tightly coupled). Single unified process, operating on a unified object-oriented data base, with subroutine invocations of digital and analog simulation algorithms. Allows efficient communication and operation between the two simulators. This methodology is good for circuits with a high degree of feedback.

- Integrated with analog core. A Spice-like simulation matrix solution with continuous current values and analog behavioral models of digital components. Allows frequency-domain analysis of the circuit, as well as time-domain analysis. It is good for smaller circuits with a limited degree of digital circuitry. These simulators are slow, therefore, relatively rare these days.

• Integrated with digital core. This methodology has analog behavioral equations embedded inside the digital simulator. It allows the passing of continuous current and voltage values on the changing time-table of event driven algorithms. This method is fast, with limited reliability, and it must be aided by a design-rule violation detection (checks for design incongruencies) algorithm. This particular method is gaining in popularity with the availability of faster computers that can run the analog mathematical equations in between events (since they are event driven) and results in a better overall programming approach that improves reliability.

Two Basic Approaches

The mentioned methodologies or approaches to the mixed-mode simulation puzzle are further categorized into two separate groups:

• Coupled or glued simulators. This approach links together separate analog and digital simulators so that information can be exchanged between the two based on synchronization and task prioritization algorithms. Within this glued approach, designers can choose between tightly coupled and loosely coupled simulators (see previous section on methodologies). This technique basically teaches two separate simulators, one digital and one analog, to talk to each other and to work together.

• Core or native simulators. These are also called extended simulators; they use either a digital or an analog core in their simulations algorithm with extensions to support the other modeling domain. In other words, both of the algorithm types necessary for analog and digital simulation are handled in one simulator. This means that when the core is analog, the simulator will treat the digital components by its analog characteristics. In other words, the core method takes an analog or digital simulator and gives it capabilities in the other's arena.

OTHER COMPLEMENTARY DESIGN TOOLS

In addition to electronic analysis tools, there are other complimentary software packages that deal with the physical aspects of a design which are influential to its electrical characteristics. Thermal analysis is one of the design tools that design engineers are using to increase the quality of their products. Considering thermal effects of densely packed components, and by moving thermal analysis to earlier stages in the design cycle where decisions on component placement, location of cooling fans, cable routing, etc. can be made, the reliability and producibility of circuit boards can be greatly increased.

Valid's thermal modeling tool, Thermostats, is integrated with its Allegro circuit board design system. The tool allows engineers to run thermal, reliability, and noise margin analysis. It answers questions about the board environment, such as the spacing between them, the velocity and direction of air flow, and the ambient temperature.

Another tool that is so important to military applications is a reliability analysis tool. A new package on the market, called Viable, lets engineers predict the reliability of the designs at the component, board, and system level. This tool also provides relative and absolute failure rates for components using the MIL-HDBK-217D/E standard.

CONCLUSIONS

The world, as a whole, is coming to depend more and me on electronics for its basic way of life, as well as for its mere existence. Engineers are incorporating 'smarts' in every electrical and electrical/mechanical device that has been around for years; from coffee makers and wrist watches to telephones and automobiles and from children's toys to land mines. The main ingredients of the 'smarts' that engineers are so carefully inserting into virtually all apparatus around us are digital chips, crammed with thousands of gates which make up the flip-flops, shift registers, multiplexers, decoders, etc. that are the basis for programmable logic arrays, programmable gate arrays, digital signal processing, applications specific integrated circuits, microcontrollers, and microprocessors, etc. These make new and smarter devices that perform amazing functions. All this only means that the circuits that every electrical engineer will be faced with will be one of a mixed-discipline or a mixed-mode circuit. So, it has become imperative to have the two simulating packages, digital and analog simulators, integrated into one.

	PRODUCT	MANUFACTURER	METHODOLOGIES	COMPUTER PLATFORMS	* PRICE ($)
COUPLED SIMULATORS	PRECISE	EE ENGINEERING	Unified Directly coupled	Sun. Apollo, DEC	30,000
	SABER/CADAT	ANALOGY	Tightly Coupled	Sun. Apollo, DEC	50,000
	A/D LAB	DAZIX	Unidirectional	Sun. Apollo, DEC	18,000
	MSPICE	META SOFTWARE	Loose Bidirectional coupled I	Sun. Apollo, DEC	15,000
	VIEWSIM	VIEWLOGIC	Tightly Coupled	Sun. Apollo, DEC	25,000
	SABER/VERILOG	CADENCE DESIGN SYS.	Loose Bidirectional coupled II	Sun. Apollo, DEC	37,000
CORE SIMULATORS	SPICE+	VALID LOGIC	Integrated With Digital Core	Sun. Apollo, DEC	35,000
	PSPICE	MICROSIM	Integrated With Analog Core	Sun. Apollo, DEC, IBM PS/2, MAC II	7,000
	SABER	ANALOGY	Integrated With Analog Core	Sun. Apollo, DEC	28,000

* 1989 figures

Figure 1. Mixed-mode simulators, typical industry use of methodologies

BIBLIOGRAPHY

1. "Special Guide to Software, Systems, and Applications," IEEE Spectrum, November 1990.

2. Digest of Technical Papers, IEEE International Conference on Computer-Aided Design, 1989.

3. "Mixed Analog-Digital Simulators," Electronic Design News (EDN), July 1989.

4. Tuinenga, Paul W., SPICE, Printice Hall, Englewood Cliffs, NJ 07632, 1988.

5. Bowerman, Robert G. and Fertig, R. T., Engineering Workstations, Van Nostrand Reinhold Co. Inc., 1988.

6. "Toolset Targets Analog and Mixed-Signal IC Designs," Computer Design, November 9189.

7. "EDA-A SuccessStory in Three Decades," Computer Design, January 1991.

8. "Analog and Mixed-Signal Design Demands Automated Tools," Computer Design, December 1989.

9. Telephone conversations and/or meetings with Richard Davis and Cheung F. Lam, Valid Logic Systems and Elliot Rosenblatt, Sun Microsystems.

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